A Fundamental Study on a Development of the System for Approximate Estimation of Ventilatory Threshold based on Fourier Transform of Breathing Curved Line.

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The purpose of this study was to develop the system for approximate estimation of ventilatory threshold (VT). This system for approximate estimation of ventilatory threshold was based on the fourier fourier transform of breathing information (Breathing Curved Line).

In this system, VT of subject was making decision by ventilatory accelation, measured by energic metabolism measurement system, based on Davis reports. In addition. a breathing curved line detectted by an using of thermintor was transformed to spcturm by fast fourier transform (FFT).

This system led us to decide ;

1) In case that the level of exercise work load was below VT level, the spectrum involved various components of frequency was detected.
2) In case that the level of exercise work load was beyond VT level, the spectrum which the peak component of frequency corresponded to ventilatory frequency cleared was detected.

Key Words : Ventilatory Threshold / Fast Fourier Transform / Spectrum

1. Introduction-Background of this study

Recently, a necessity of exercise or sports has extended into a social life step by step. But in this background, we have looked toward to a not only agreeable social change as increase in free time, but also a big social problem such as a marked and conspicuous increaese in a diseases of adults. For example, preceded studies reported that portliness originated by an insufficiency of exercise had transformed (Metastasized) to a diseases of adults as a disabates or heart diseases.

In a prophylaxis or rehabilitaion of a diseases which caused by an insufficiency of exercise, it is very important that an exercise prescripiton or exercise therapy has been carried out, and an exercise loading system represented by a bicycle ergometer has been taken in a field of a prophy-laxis or rehabilitation of a diseases.

A bicycle ergometer is shaped like a bicycle and an exercise loading system. And in exercising by an using of an ergometer, it is easy to determine the quantity of the work load intensity and safe in exercising because of no dengerousness to fall down by sittig of the saddle of a bicycle. Moreover, it is easy to install an electro cardiogram or electro pulsegram because an upper part of the body is stabilized by sitting.

So far forth, a controlling of exercise work load in ergometer is based on heart rate, which liner changed with the changing of exercise work load, detected. by the electro cardiogram or electro pulsegram. And the level of exercise is set on the work load which corresponds to 60% heart rate max (60% HRmax). In general, heart rate max is calculated from simplified estimation which is 220—age of exerciser. Moreover, this level of the work load is utilized into not only ergometer exercise but also all of exercise and training.

Many a proceded studies reported the advantage

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of this work load level corresponding to nearly 60% HRmax in exercise, and recently a few proceded studies reported this level of the exercise work load was nearly equal to some threshold, which lactate with exercise surpulse created. As is generally, this threshold is called "anaerobic threshold (AT)", which is an evaluation for safety and effectiveness in exercising, is applied to the field of exercised therapy or rehabilitation.

The making decision of AT is based on the evaluation of a blood lactate accelation with exercise (Lactate Threshold), and the evaluation of a ventilatory accelation (Ventilatory Threshold). But to make a practicable process of these methods, very expensive system and very highly-developed technic of evaluation is demaned. And it is nearly impossible of these methods to popularized wholly in a field of exercised therapy or rehabilitation.

For that reason, various simplified estimation of AT was developed. For represented example Conconi reported[7] that the threshold, which running speed had broken away from regression-line between running speed and heart rate, had been nearly equal to the work load of AT level in tredmill running.

James reported[2] AT could be estimated from nonlineier increase in respiratory frequency with regular increase in exercise work load.

And in another study, Nakamura reported[7] AT could be estimated from the chang on coehrence of the variance of work load and heart rate response.

And this study reports a new methods on estimation of AT —approximate—, and introduce of the system for estimation of AT, based on a breathing information (Breathing Curved line) fourier transformed.

And in this study, because the estimation of AT is based on the evaluation of VT, the expression as VT is used.

2. Method —Constructing of system and experiment—

Fig-1 and photograph-1, 2 shows the system, which estimates VT approximatly, and energic metabolism measurement system for the making decision of VT in subject.

The system, which estimates VT approximatly, is made up with 3 functions, detecting, transmitting and receiving, and analizing of breathing curved line.

On the mask (phote-1), which subject installs, the thermistor is set on. And by an using of it, breathig curved line, brought about by the changing of gas temparature with breathing, is detected and transmitted to the recieving apparatus by the telemetory system, in addition through with the aid of a circuit, taked into the personal computer (NEC9801), and transformed to power spectrum by an using of fast fourier transform (FFT)[6] functioned in the hard disk attached the computer

The experiment was practiced by this system and energic metabolism measurement system jointly. Subject installed above-mentioned mask, which the thermistor had been set on, and exercised peddaling work by an using of the bicycle ergometer under the exercising condition of incremental gradual step loading, which loaded 25watt/min regularly. Subject continued to exercise peddaling work until subject was not able to keep exercise under the above-mentioned condition. And ventilatory response or accelation of subject was measured by the above-mentioned metabolism measuerment system, and VTof subject was made a decision.

The standerd of the making a decision of VT was based on Davis report,[1]

1) Nonliner increase in $\dot{V}E$ (Ventilation Expire) and $\dot{V}CO_2$ (Ventilation VCO_2)

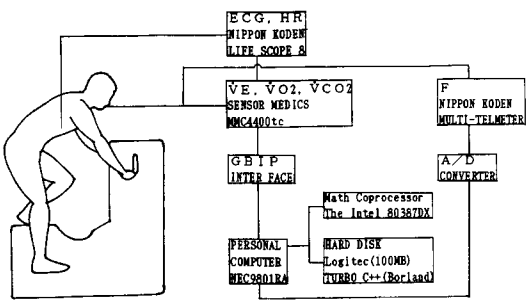


Fig-1 : A making of system, which approximatly estimated ventilatory threshold, and metabelism measurement system.

2) Increase in $\dot{V}E / \dot{V}O_2$ without increase in $\dot{V}E / \dot{V}CO_2$

3) Nonliner increase in R ($\dot{V}CO_2 / \dot{V}O_2$).

VT was decided by these standard (Fig-2).

In addition, to find out the specific quality of this system which used the thermistor, we compared the breathing in rest with the breathing in case volume (Tidal Volume) with each ventilation was changed consciously.

3. Results

Fig-3 shows a breathing curved line and its spectrum measured and analized by an using of the above-mentioned system for approximate estimation of VT. Sampling time of data was set on 20m seconds and sampling periods of breathing curved line was set on 40. 96 seconds. And power spectrum was indicated by a relative estimation as the most

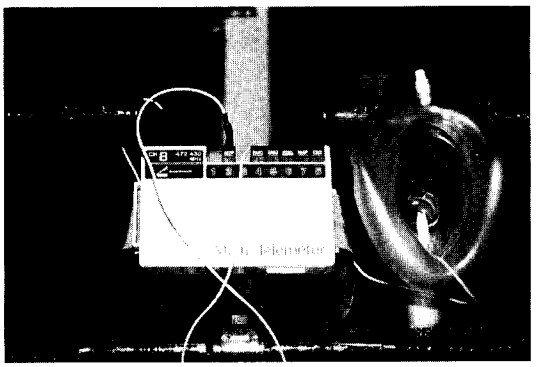
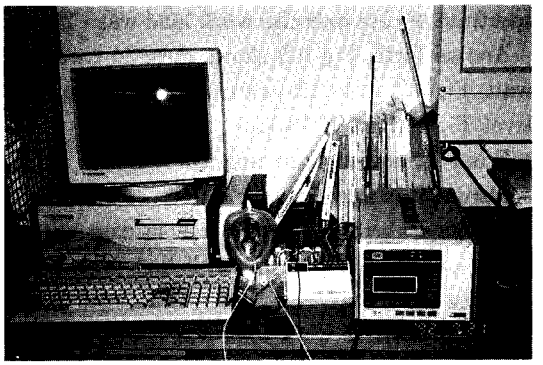


PHOTO-1



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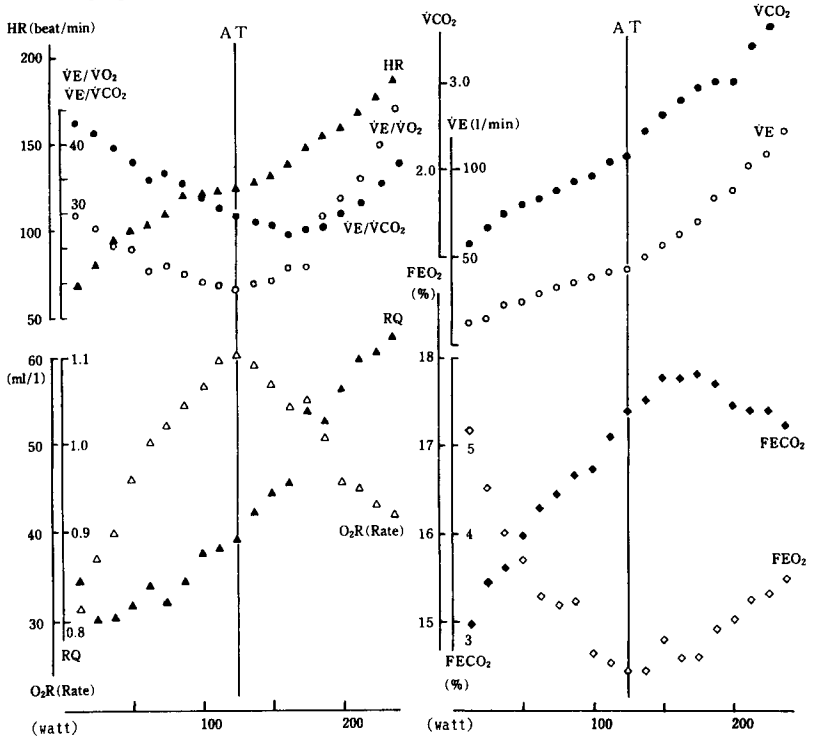

Fig-2 : Example of anarobic threshold (AT=Ventilatory threshold : VT) determination. AT (VT) was dererminated by nonliner increase in $\dot{V}E$, $\dot{V}CO_2$ and RQ, and increase in $\dot{V}E/\dot{V}O_2$without increase in $\dot{V}E/\dot{V}CO_2$

intensive frequency was 100 percent. Moreover frequency indicated was under 6.25hz.

The physiological charactaristics of subject in this example was in those follows. Height was 168.0 cm and weight was 60.0kg. $\dot{V}O_2$max was 3.71l/kg* min (Relative $\dot{V}O_2$max was 61.80ml/kg*min). VT was the level of 55.01%$\dot{V}O_2$max (Relative $\dot{V}O_2$ was 34.00ml/kg*min) and heart rate of VT level was 138 bpm (beats per minute), exercise work load was 150watt.

Fig-3(1) shows a breathing curved line and its spectrum in case exercise work load was 25 watt.

And so forth, Fig-3(2) shows these in case of 75 watt, Fig-3(3) is in 150 watt, that had been a VT level, Fig-3(4) is in 200watt.

From points of breathing curved line and its spectrum, it is suggested the difference between the spectrum of breating curved line in case exercise work load was below VT level and that in case exercise work load was beyond VT level. And in case that exercise work load was below VT level, the most intensive frequency which was equal to the respiratory frequency, was not clear and various components of frequency was observed. But in case that exercise work load was beyond VT level, the most intensive frequency, as an above-mentioned, which was equal to respiratory frequency, was clear and another components of frequency was less observed than that in case exercise work load was below VT level.

Fig-4(1) shows breathing curved line and its spectrum in rest (in case having been regular). And fig-4(2) shows that in case volume with each ventilation had been changed (in case having been irregular). Setting condition of sampling time and sampling periods was equal to in case of fig-3. But frequency indicated was changed from 6.25hz to 3. 175hz because of clearing the relationship between the most intensive frequency and respiratory frequency. And Table-1 shows tidal volume, measured by metabolism measurement system, with each breathing curved line indicated in fig-4(2).

Tidal volume of first curved line was 2.92 liter per 8 seconds (2.92l / 8sec), and so forth, that of second curved line was 0.74l / 4sec, third curved line was

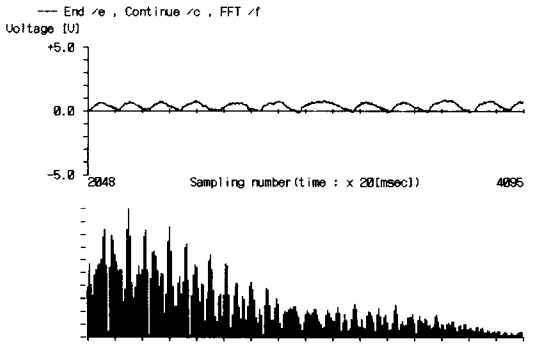

Fig-3 (1) : Breathing curvrd line and its spectrum, after 1 min from start to exercine (25watt)

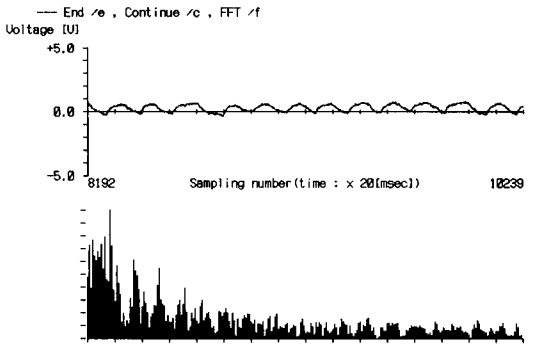

Fig-3 (2) : After 3 min (75watt)

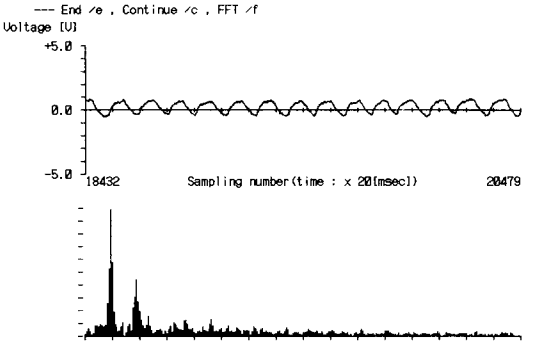

Fig-3 (3) : After 7 min (150watt ; VT level)

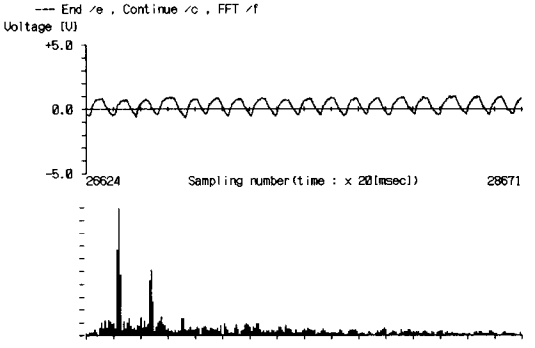

Fig-3 (4) : After 9 min (200watt).

0.46l / 1sec, forth curved line was 0.66l / 2sec, fifth was 1.22l / 4sec, sixth was 2.21l / 6sec, as follows, 0.57l /4sec, 0.22l / 2sec, 0.32l / 1sec, 0.31l / 2sec, and last curved line indicated in fig-4(2) was 2.99l / 5sec.

From points of this kind, it is thought that tidal volume could be estimated qualitatively by breathing curvrd line taken by thermistor used in this system. Moreover it is suggested the difference on spectrum of breathing curved line between the case having been regular and the case having been irregular. In case breathing curved line had been nearly regular, the main component of frequency in power spectrum transformed was clear. Bnt in breathing curved line had been irregular, various periodic components of frequency in power spectrum was detected.

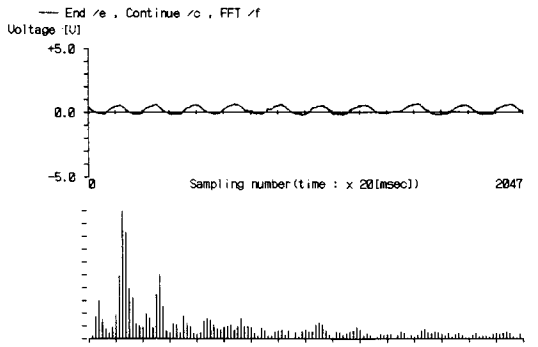

Fig-4 (1) : Brathing curved line and its spectrum in rest-in case having been regular.

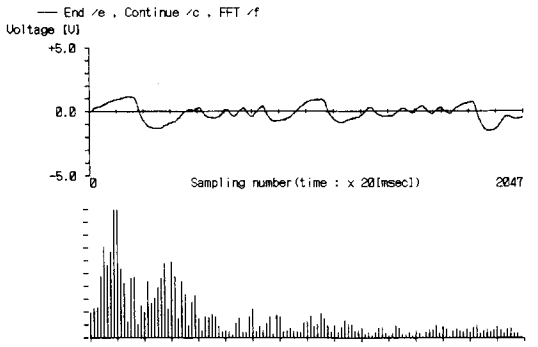

Fig-4 (2) : Breathing curved line and its spectum in case volume had been changed with each ventilation-in case having been irregur.

4. Discussion

At the begining, the concept of ventilatory threshold has been thought that increase in exercise work load had brought about a mobilization of anaerobic metabolism, and a mobilization of anaerobic metabolism had brought about an excess creation of lactate (LT) in muscle, moreover an excess creation of lactate had brought about ventilatory accelation (VT). But against this concept, various problems were pointed out. For represented example, it was pointed out that ventilatory accelation was observed even if be McArdle's disease which lactate had not been produced in muscle at all. And it is thought that first-mentioned concept of ventilatory threshold has nôt been an established theory but an accepted opinion.

But in this paper, a debate about this concept would be omitted, with the aim of thinking about the function and validity of the system for estimation of VT, we have observed a mechanism of ventilatory accelation from ponit of an accepted opinion that ventilatory accelation had been originated by an execss creation of lactate with a modilization of anaerobic metabolism.

As above-mentioned, one of the standerd to make a decision of VT from point of ventilatiory accelation is nonliner increase in $\dot{V}E$. And $\dot{V}E$ is the

Table-1 : Tidal volume, corresponding to each breathing curved line idicated in Fig-4 (2)

No. of curve	Volume of curve (liter)	times of curve (seconds)
1 st	2.92	8.0
2 nd	0.74	4.0
3 rd	0.46	1.0
4 th	0.66	2.0
5 th	1.22	4.0
6 th	2.21	6.0
7 th	0.57	4.0
8 th	0.22	2.0
9 th	0.32	1.0
10 th	0.31	2.0
11th	2.99	5.0

product of V_T (Tidal Volume) and F (Respiratory Frequency). In the early stage of increase in $\dot{V}E$ with linier (Step) increase in exercise work load, the increase in $\dot{V}E$ is depended on the increase in V_T and F, and in the middle stage of the increase in $\dot{V}E$ with more increase in exercise work load in comparision with the early stage of that, the increase in $\dot{V}E$ is depended on the increase in F, and V_T reaches to the upper limit in exercise and V_T converges into the upper limit.

Wasserman reported[13] that considerable respiratory frequency had been a special feature of metabolic acidosis. And Koike et al reported[9] metabolic acidosis had been equal to AT (Anaerobic Threshold).

From these points, James et al reported[2] it had been possible to estimate VT by F movement, and Nemoto et al pointed out[8] that in case that exercise work load was beyond VT level, the rate of increase in F had been higher in comparision with that in case exercise work load was below VT level, and indicated that it had been possible to estimate VT by the rate of increase in F. But Shimana et al reported[9] that to estimate VT by F had been restricted by various factors inserted with setting of exercise condition. And this argument has not been concluded as yet.

From physiological points, in thinking about the principle of the system to estimate VT approximatly by spectrum of breathing curved line transformed by fast fourier transform, in case of assuming that the level of the exercise work load dose not reach to VT level, because of the low level of exercise work load, V_T increases with the same period of increase in exercise work load. But in this condition, air velocity or volume with ventilation in comparision with an aera of the airway, is in limit, and an equalization of an autonomic nervous system is chaotic, and V_T with each ventilation is not supplied with a definite volume, consequently it is assumed that power spectrum which has indicated a frequency of breathing curved line has various frequency band. But with increase in exercise work load, and that is beyond VT level, because of the neccesity of enough and concecutive supply of O_2 (Oxygen), V_T with each ventilation increases, and the velocity or volume through the airway with each ventilation is restricted physically from the relation of the aera of the airway, and volume with each ventilation is definite, from these points, it is assumed that power spectrum which has indicated a frequency of breathing curved line changes in comparision with spectrum in case exercise work load is low level-not reached to VT level.

About this points, Shionoya et al reported[10][11] that V_T had been supplied in irregular (not definite) in case exercise work load below VT level, but in regular (definite) in case beyond VT level.

In general, VT (AT) was investigated in the field of physiology (Exercise physiology involved the application of rehabilitation or exercised therapy), and then its evaluation was qualitative, not quantitative. For example making decision of VT is carried out by a qualitative standerd as increase in $\dot{V}E$ or $\dot{V}CO_2$, or increase in $\dot{V}E / \dot{V}O_2$ without increase in $\dot{V}E / \dot{V}CO_2$, And then because of only to evaluate qualitativly of VT, the mechanism of VT is not all clear, an application of VT is based on the rule of the experience. And next, in order to thinking mechanically about the system for estimating of VT approximatly, VT had been evaluated quantitatively, from point of airway dynamics.

Fig-5 and Table-2 shows the relationship between exercise work load and air velocity in the airway with ventilation and reynolds number in subject. Air velocity in the airway with ventilation was decided from the differential calculus of $\dot{V}$ which received from the metabolism measurement system, and reynolds number was decided as a basis on the date of Weible,[3][4][12] for example of the length of the airway and the dinameter of airway.

In thinking about the relationship between the exercise work load and air velocity in the airway and reynolds number with ventilation, it is suggested that on nearly 100 or 125 watt of exercise work loads, the reynolds number has been beyond the critical number. And the relationship between the exercise work load and Reynolds number has been approximated to the 2 dimentionl regression as

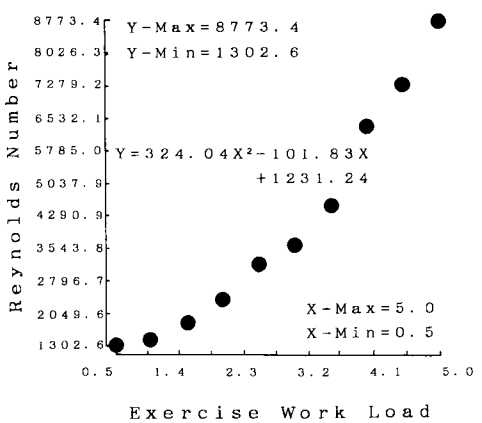

Fig-5 : A relationship between exercise work load (X-axis; units is kp) and reynolds number (Y-axis) of a subject. A relationship was "y=324.04X2−101.83X+1231.24"

Table-2 : Reynolds number of ventilation in the each exercise work load.

Load (kp)	(watt)	$\dot{V}$ (1/sec)	$\bar{U}$ (cm/sec)	Re
0.5	25	0.26	105.3	1302.6
1.0	50	0.27	111.4	1377.5
1.5	75	0.35	145.8	1802.8
2.0	100	0.46	193.3	2321.0
2.5	125	0.60	243.9	3235.3
3.0	150	0.73	325.5	3696.6
3.5	175	0.89	365.4	4471.4
4.0	200	1.27	421.6	6452.8
4.5	250	1.43	587.5	7267.8
5.0	275	1.73	709.2	8773.4

$$Y=324.0X^2-101.83X+1231.24$$

And then from ponit of airway dynamics, it is suggested that at a low level exercise in comparion with exercise work load of VT level, the flow in the airway has changed from the laminar flow to the turbulet flow. In case of the laminar flow, the difference of the resistance, that the airflow flows to some section in the airway, is assumed as ΔP, ΔP is decided by the products of the resistance of the airway and velocity. And in case of the turbulet flow, ΔP is decided by the products of the resistance of the airway and a squear of the velocity. Moreover, in clinical examination, to check up a trouble in the airway it is neccesary to maintain the condition of the liminar flow in the airway, and the examination is carried out in the ventilatory condition which velocity of airflow is 0.51 / sec.

From the above-mentioned, it is suggested that the quantative transmittion of ventilation occurs earlier than the qualitative transmission of ventilation, before the mechanics of ventilation origined by VT, for example in case exercise work load is beyond VT level, V_T reaches to the upper limit of ventilation in exercise is effected by the quantitative transmission. And it is thought that the system for approximate estimation of VT is based on the mechanics of ventilation.

The assignments in future are 1) increase in subjects 2) verification of the validity of this system from point of precision airway dynamics 3) verification of the system, especially characteristics of the thermistor.

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